INTERACTION BETWEEN GLASS BATCH PARTICLES VIA POTASSIUM-BEARING INTERLAYERS

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The capillary-crystallization interaction of potassium-bearing components of a glass batch are investigated. A comparison with similar dependences for sodium-bearing components is performed. New regularities related to different solubility of components, which have not been described before, are considered. In particular, a positive effect of alkali metal sulfates, which are commonly used to accelerate the glass-melting process, on fixing the batch components is demonstrated. The behavior of the capillary-crystallization curves is analyzed for solutions of different components.

The current technology of automated glass forming imposes enhanced requirements on glass composition and structure. These properties to a large extent depend on glass batch preparation, in particular, on moistening of a homogeneous batch mixture, which is essential for producing high-quality glass. Moistening decreases the entrainment of dustlike batch particles and, consequently, stabilizes the composition of glass and increases its thermal conductivity, which facilitates its faster and more uniform heating. Furthermore, moistening prevents the segregation of batch, due to emerging forces of capillary adhesion. In [1, 2] we have published the first results of the analysis of capillary-crystallization interaction of particles via interlayers of one- or multi-component solutions of sodium-bearing compounds.

The present study continues our research in interaction between glass batch components. We used the model of a "spheroid glass particle – liquid interlayer – flat glass substrate" capillary contact to study adhesion forces. The adhesion force was measured under a periodic separation of particles. The procedure of the experiment is described in [2]. The present study investigates interaction forces as applied to potassium-bearing glass batches. We investigated the behavior of two solid glass particles connected by a capillary interlayer of a one-component solution of potassium carbonate or potassium sulfate, or a two-component solution of sodium carbonate – potassium carbonate with concentrations of 0.25, 0.50, and 1.00 M. The components in the two-component solutions were taken in equal quantities. The solution of potassium sulfate solution had concentrations of 0.25 and 0.50 M due to its low solubility in water.

Since the capillary component in a capillary-crystallization interaction depends on the surface properties of liquid,

we investigated the surface tension of potassium- and sodium-bearing solutions in one- and two-component systems using the method of maximum pressure in a gas bubble.

During batch moistening, water drops penetrate into the batch and produce capillary interlayers between particles of sand, dolomite, and other insoluble components. Water reacts with soluble components and produces solutions which form liquid interlayers as well.

Let us compare the behavior of capillary interlayers consisting of different salt solutions. Figure 1 shows the dependences of capillary-crystallization adhesion strength on contact duration for aqueous solutions of potassium carbonate, sodium carbonate, and potassium sulfate for a spheroid model particle of diameter 2.6 mm.

With a concentration of 0.25 M, the capillary segment is more parallel to the abscissa axis than in the solution with higher concentrations, and evaporation lasts shorter. However, the initial adhesion force under a low concentration is higher, except for the curve of K_2SO_4 (0.50 M). Under concentrations of 0.50 and 1.00 M the force increment is more intense; crystallization presumably starts from the first seconds and increases the strength of contact. After reaching a maximum, the force of adhesion sometimes decreases, which can be attributed to the presence of residual liquid not on glass particles, but on emerging crystals. Potassium sulfate typically has a higher initial force and the force of its adhesion intensely grows with time. This is due to the limited solubility of potassium sulfate in water (approximately 0.6 M at 20°C). Consequently, crystals are formed from the first minutes of the experiment due to the saturation of the solution. Compared to potassium carbonate, potassium sulfate facilitates a stronger adhesion of particles and the initial strength is equal to 4.5 – 5.0 mN.

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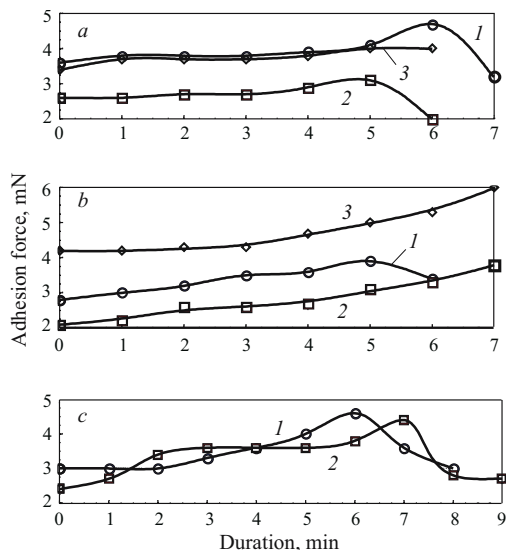
Fig. 1. Dependence of capillary-crystallization adhesion strength on contact duration for aqueous solutions of Na_2CO_3 (*1*), K_2CO_3 (*2*), and K_2SO_4 (*3*) at concentrations of 0.25 (*a*), 0.50 (*b*), and 1.00 M (*c*) (the weight of the liquid at the initial moment is equal to 0.00455 g).

Comparing the obtained curves with the data on sodium sulfate [2], we note that both curves have a similar course, but the values of the initial and maximum adhesion force for sodium sulfate are significantly lower than for potassium sulfate. The surface tension of sodium sulfate is higher than that of potassium sulfate; therefore, it is impossible to account for the initial strength difference only in the context of capillary force. Consequently, the presence of sulfates in a glass batch increases the probability of particles becoming fixed after mixing and moistening, compared with soda. This peculiarity ought to be used to accelerate the glass melting process.

Sodium and potassium ions in glass production are usually introduced via soda and potash. The solution concentration for the soda-potash system does not influence the force of adhesion at the initial moment of measurement, which is equal to about 3.0 mN (Fig. 2). Under low concentrations the force of adhesion in the initial period varies insignificantly. Under a concentration of 1.00 M, the adhesion force intensely grows from the first minute in most curves. At any concentrations the force of adhesion is higher in the experiments where the initial solution drop has a smaller weight.

In general, the course of the curves corresponds to those studied earlier [2]. Comparing them with the data in [1], we observe several differences, primarily related to the larger size of the spheroid model particle (4.8 mm, in difference to 2.6 mm in the present study), different weights of capillary liquid, and different methods for depositing solution drops. In our experiments we were unable to detect an abrupt increase in the capillary contact strength at the final stage of interaction.
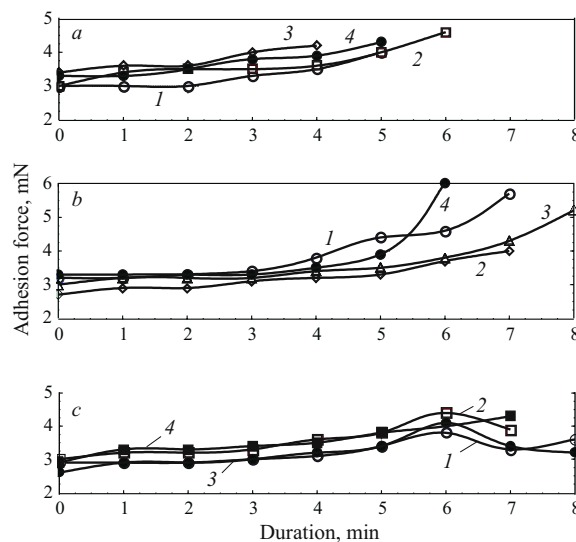

Fig. 2. Dependence of capillary-crystallization adhesion force on contact duration for aqueous solution of $Na_2CO_3 - K_2CO_3$: (*a*) concentration 0.25 M; *1*, *2*, *3*, and *4*) the weight of the solution drop 0.00515, 0.00545, 0.00335, and 0.00395 g, respectively; (*b*) concentration 0.50 M; *1*, *2*, *3*, and *4*) the weight of the drop of solution 0.00485, 0.00615, 0.00630, and 0.00465 g, respectively; (*c*) concentration 1.00 M; *1*, *2*, *3*, and *4*) the weight of the drop of solution 0.00500, 0.00295, 0.00315, and 0.00225 g, respectively.
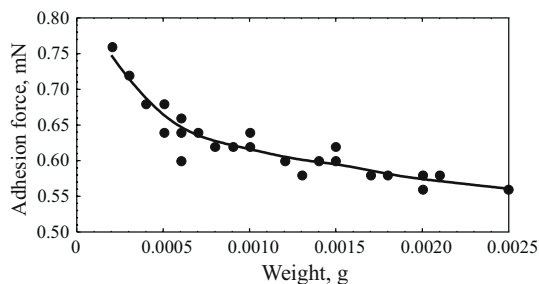
Fig. 3. Dependence of particle adhesion force on the quantity of capillary liquid (capillary liquid – water; spheroid particle diameter 2.6 mm).

The course of the curves in Figs. 1 and 2 can be interpreted as follows: variation of capillary adhesion force depending on the volume of liquid (Fig. 3), variation of surface tension of solutions depending on their concentration (Fig. 4), and variation of the force of capillary adhesion between a spherical and a flat particle depending on the distance between them (Fig. 5).
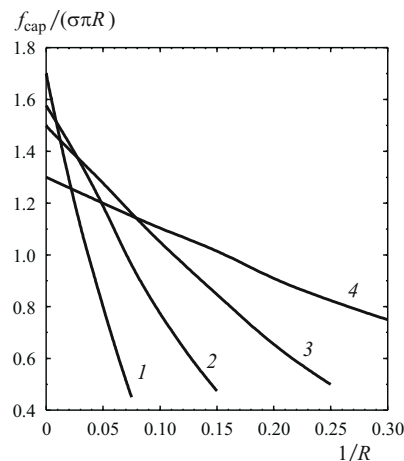
Analyzing the general course of capillary-crystallization interaction of particles connected by an interlayer of aqueous salt solutions, the following comment should be made. Water, as is already known, participates in a purely capillary interaction [1]. Due to evaporation, the volume of a liquid cup decreases with time. As a consequence, the interaction force grows during the experiment [1, 2], since the capillary force
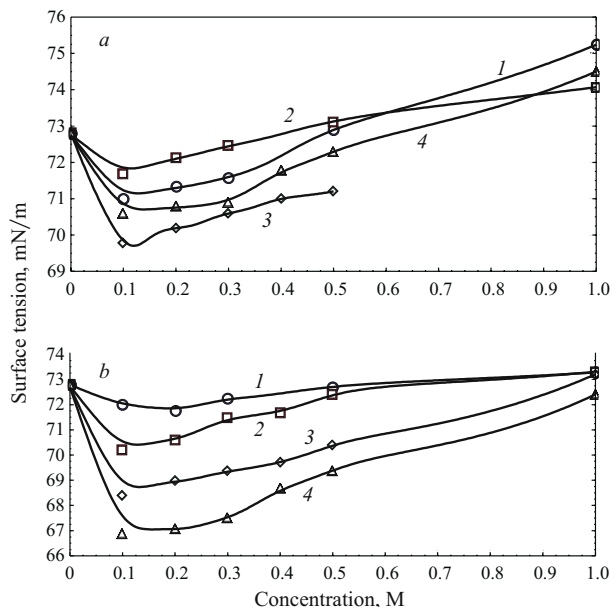
Fig. 4. Dependence of surface tension of solutions on their concentration: (*a*) one-component solutions; *1*, *2*, *3*, and *4*) Na_2CO_3, Na_2SO_4, K_2SO_4, and K_2CO_3, respectively; (*b*) multicomponent solutions; *1*, *2*, *3*, and *4*) $Na_2SO_4 - Na_2CO_3$, $K_2SO_4 - K_2CO_3$, $Na_2CO_3 - K_2CO_3$, $Na_2SO_4 - K_2SO_4$, respectively.

Fig. 5. Dependence of capillary force of adhesion of a sphere to a plane on the distance between them with perfect wetting and different quantities of liquid [3] (relative values of force $f_{cap}/(\sigma \pi R)$, distance $1/R$, and volume $V/(\pi R^3)$ are given): *1*, *2*, *3*, and *4*) $V/(\pi R^3) = 0.0015$, 0.01, 0.03, and 0.01, respectively.

increases as the volume of liquid decreases (Fig. 3). At the same time, an increasing concentration of salt changes the surface tension; the curve has a minimum (Fig. 4) that corresponds to the concentration of $0.1 - 0.2$ M, after which the surface tension increases.

In our experiments we used solutions of higher concentrations (0.25, 0.50, and 1.00 M). Therefore, the superposition of these two effects should lead to an increment in adhesion force from the first minutes of the experiment. However, the initial rise of the curves proved to be insignificant. This is possibly due to the fact that under gradual water evaporation, salt crystals start precipitating on the particle surface. Therefore, when particles are brought together, they have no direct contact. A solid film is formed, whose thickness increases as the volume of the solution keeps decreasing. It is known [3] that as the clearance increases, the capillary force decreases (Fig. 5); the smaller the quantity of capillary liquid, the more intense is this decrease. Consequently, depending on the concentration and the weight of liquid, a particular effect prevails at the initial moment, accordingly, either experimental curves are parallel to the abscissa axis, or the adhesion force grows from the first minute of the experiment.

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